High-radiance LDP source for mask inspection

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USHIO INC. / *Fraunhofer ILT

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USHIO

Lighting Edge Technologies

Thank you
50th Anniversary

I N D E X

- Basic principle
- Brightness
- Stability and reliability
- Cleanliness
- Summary

10x brighter source is wanted.

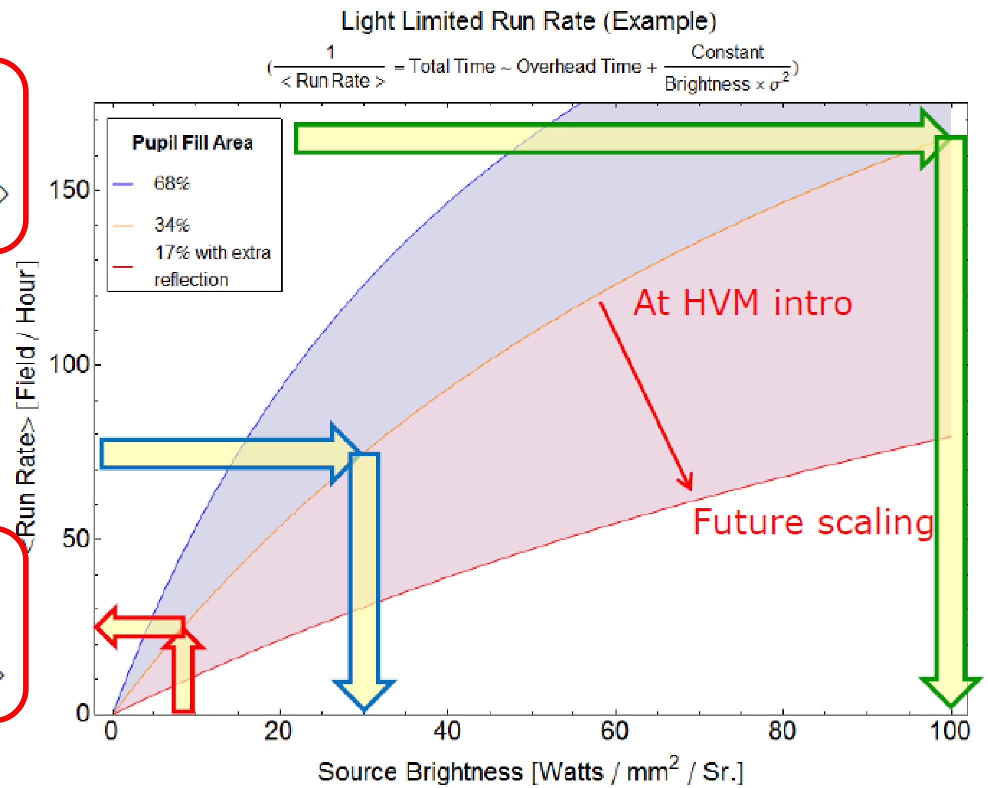
Why Brightness Matters (canonical AIMS model)

Estimates by Michael Goldstein (Intel)

This is what the industry *wants*. ⇨ ⇨ ⇨

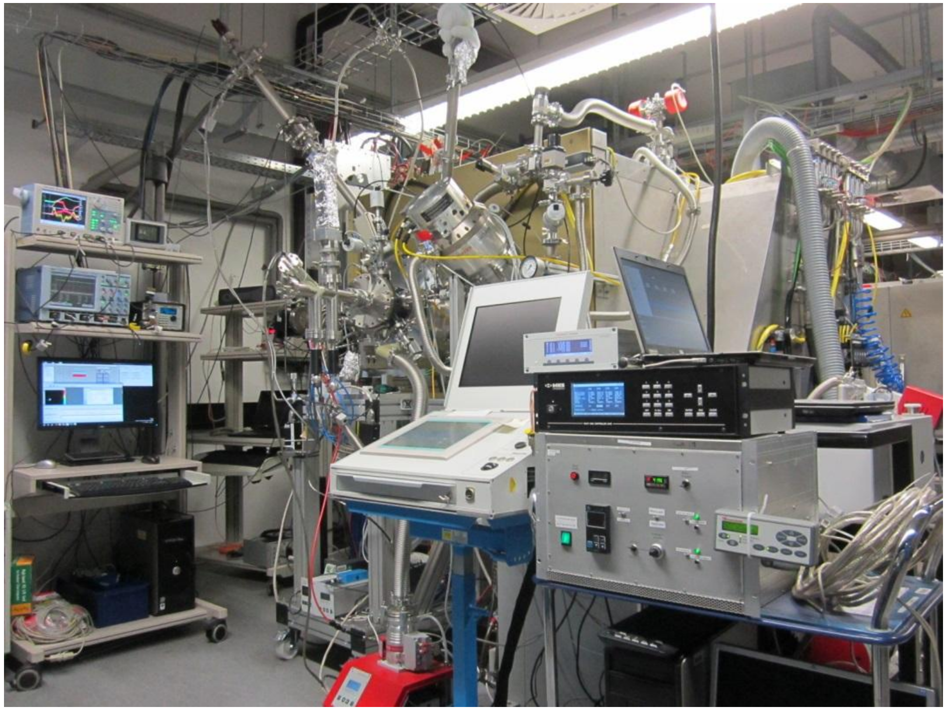
This is the need. ⇨ ⇨ ⇨

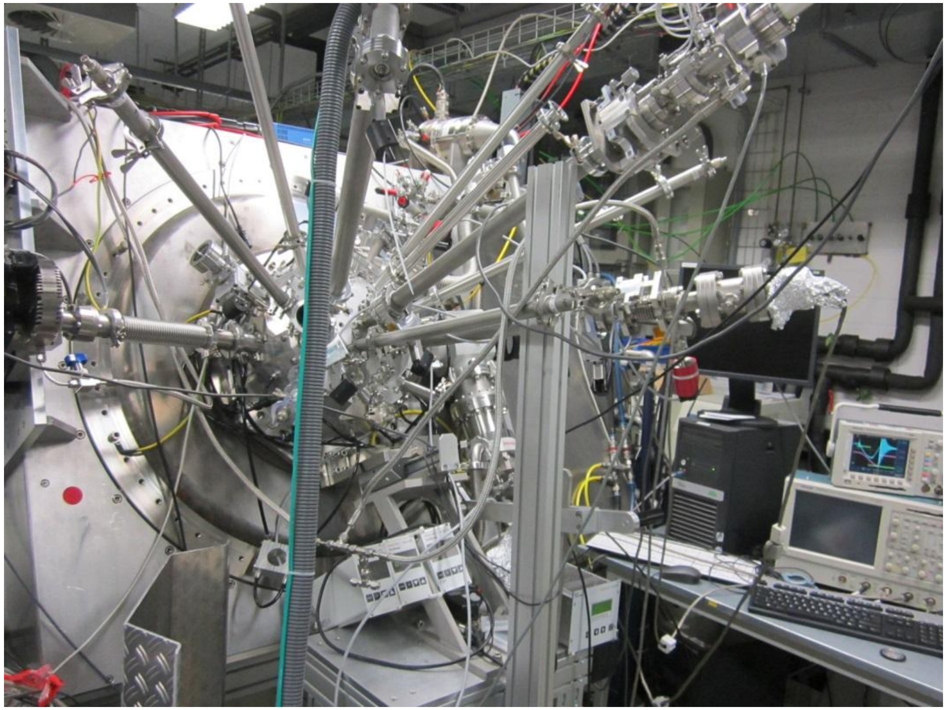
This is about where we are. ⇨ ⇨ ⇨ ⇨



Mark Phillips, "Enabling EUVL for HVM Insertion",
2013 International Workshop on EUV and Soft X-Ray Sources, Nov. 4, 2013, Dublin, Ireland

R&D sources in Germany

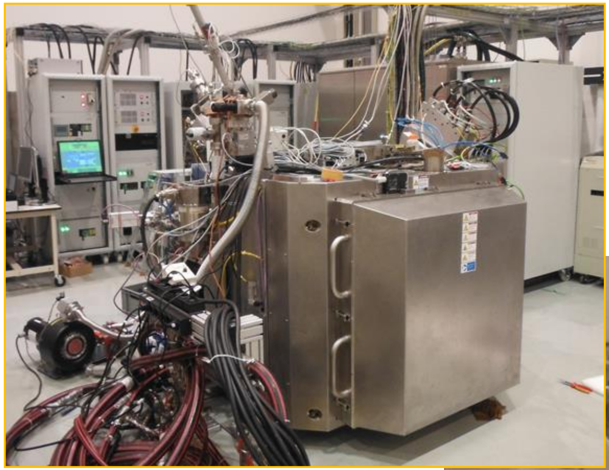




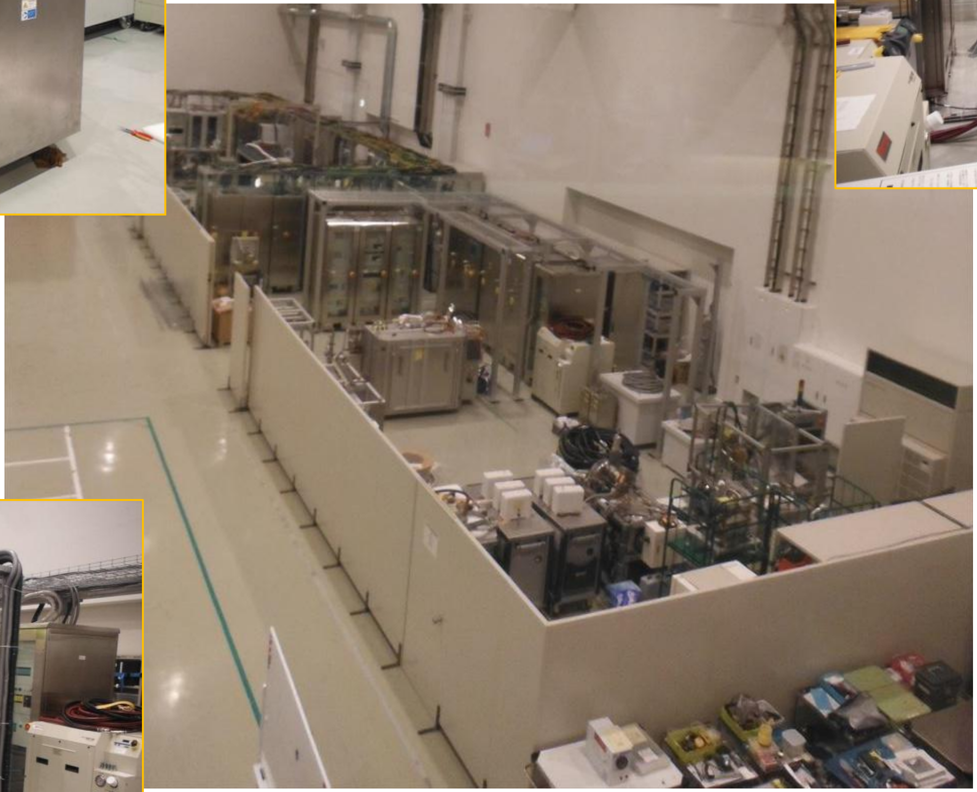
- Component development
- Preliminary testing

- Physics-related experiment
- Efficiency and stability

Product development sources in Japan



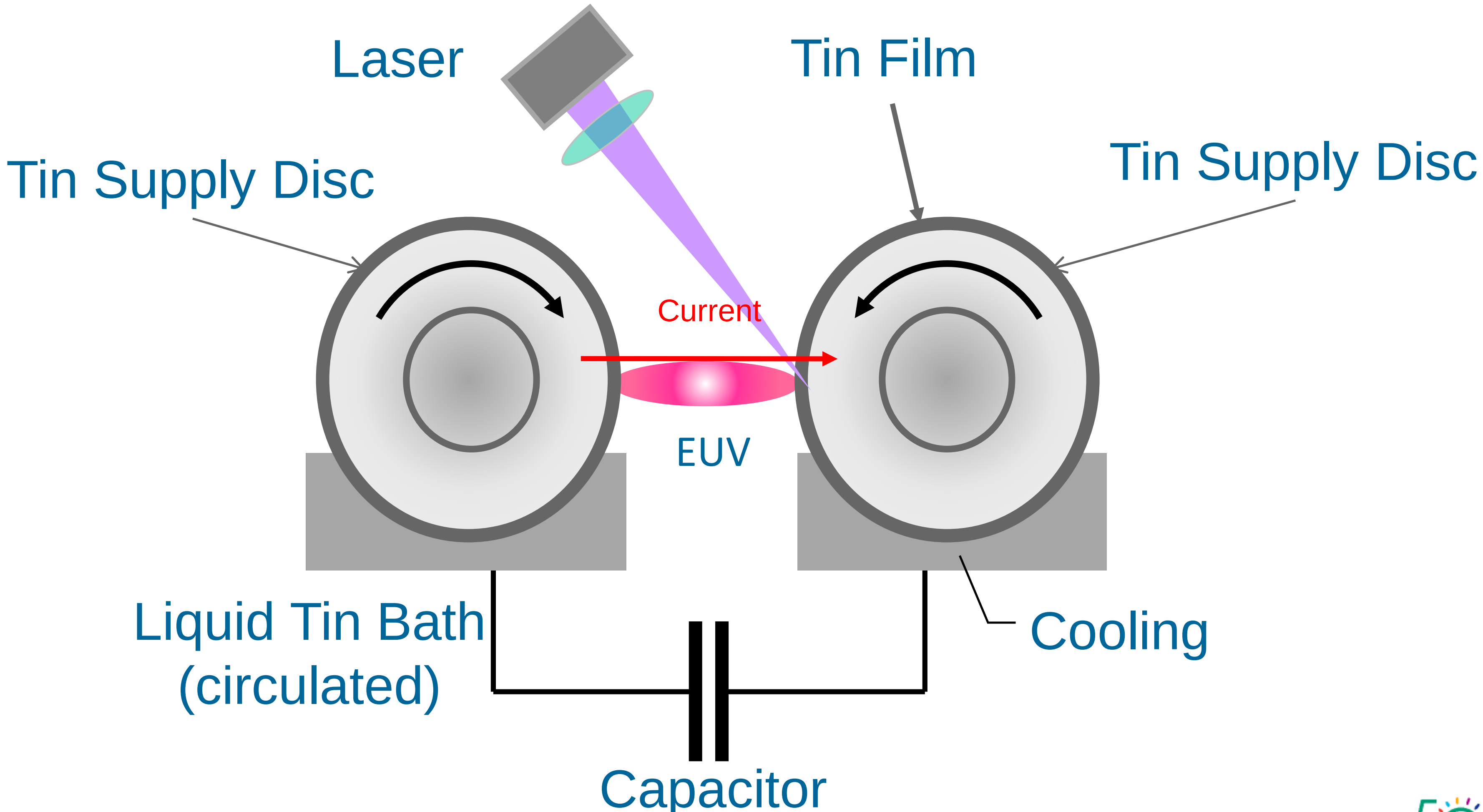
Reliability test



Platform for prototype

System development

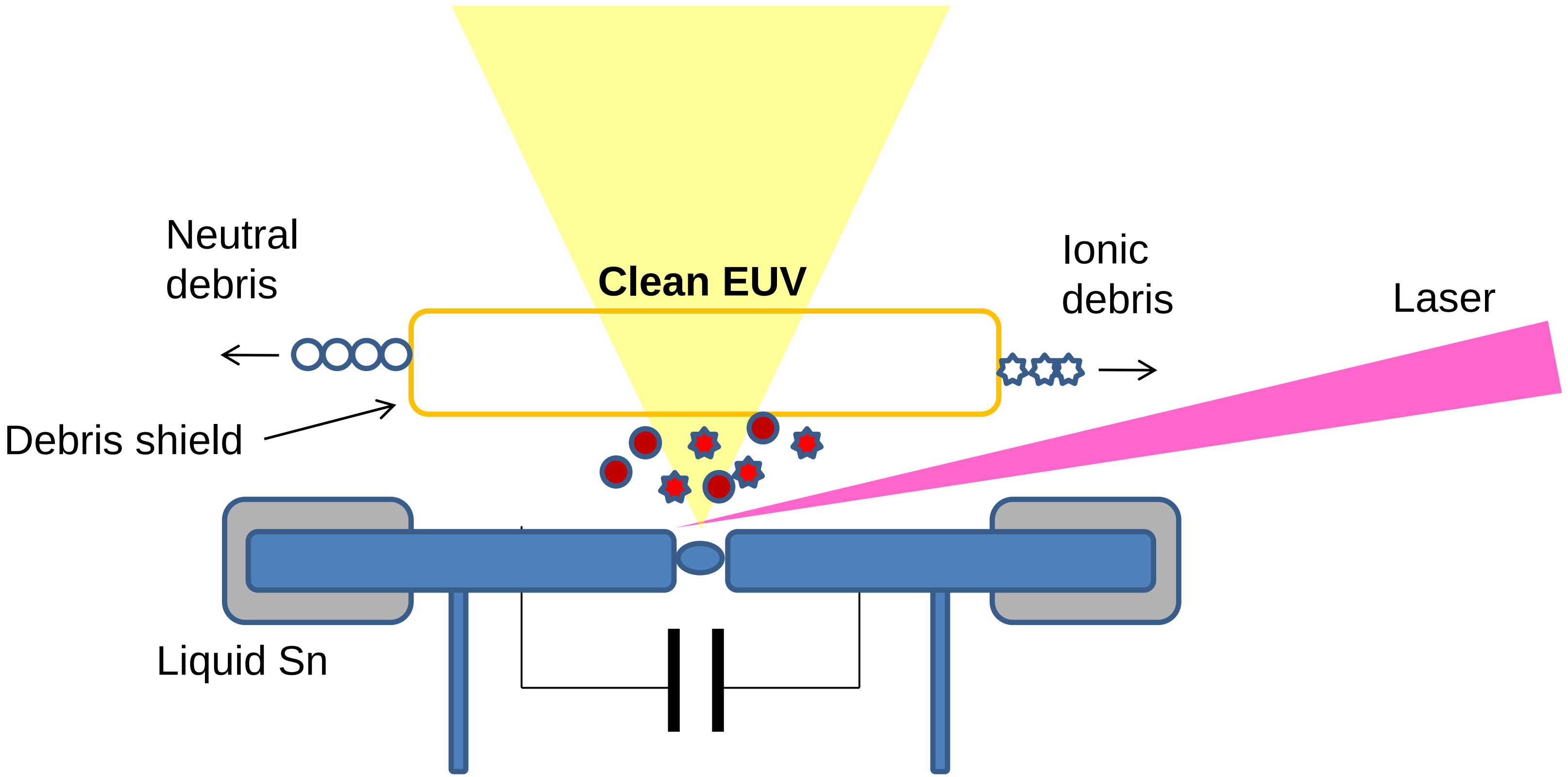
Sn+Laser+Discharge=high-radiance LDP



LDP provides high-radiance, clean and stable EUV photon

Neutral debris
(Macro/microscopic particles, gaseous debris)
- Completely stopped by debris shield

Ionic debris
(Charged particles)
- Mostly stopped by debris shield



I N D E X

- Basic principle
- **Brightness**
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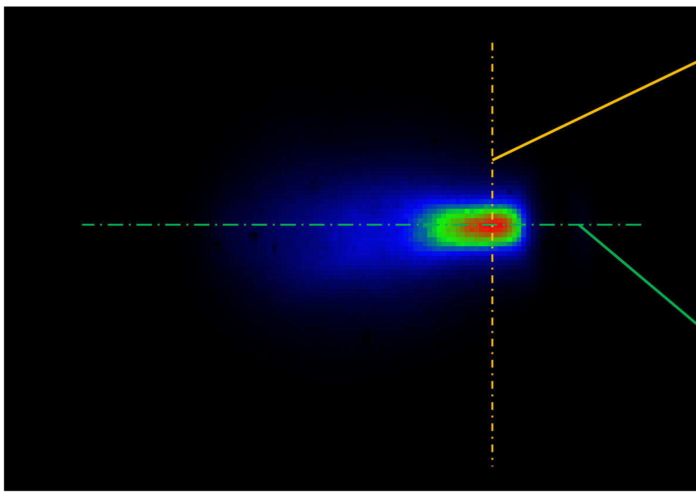
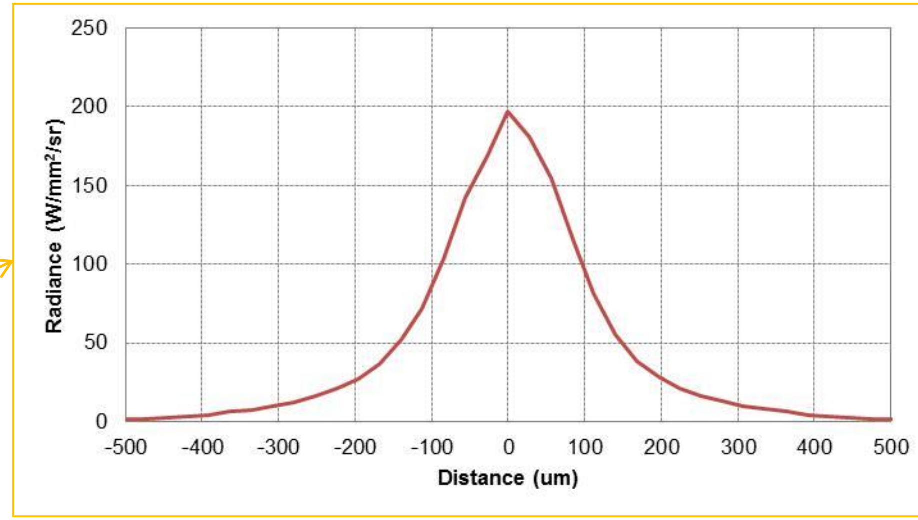
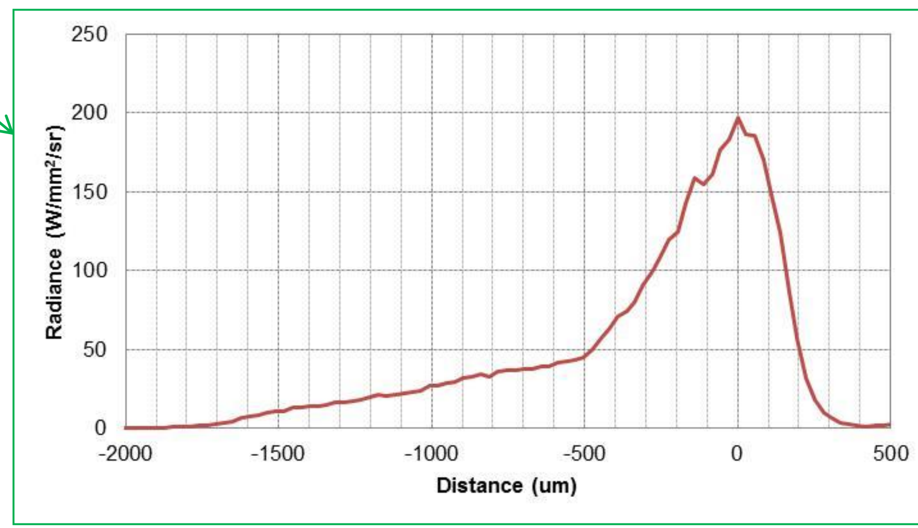
EUV emission image and profile





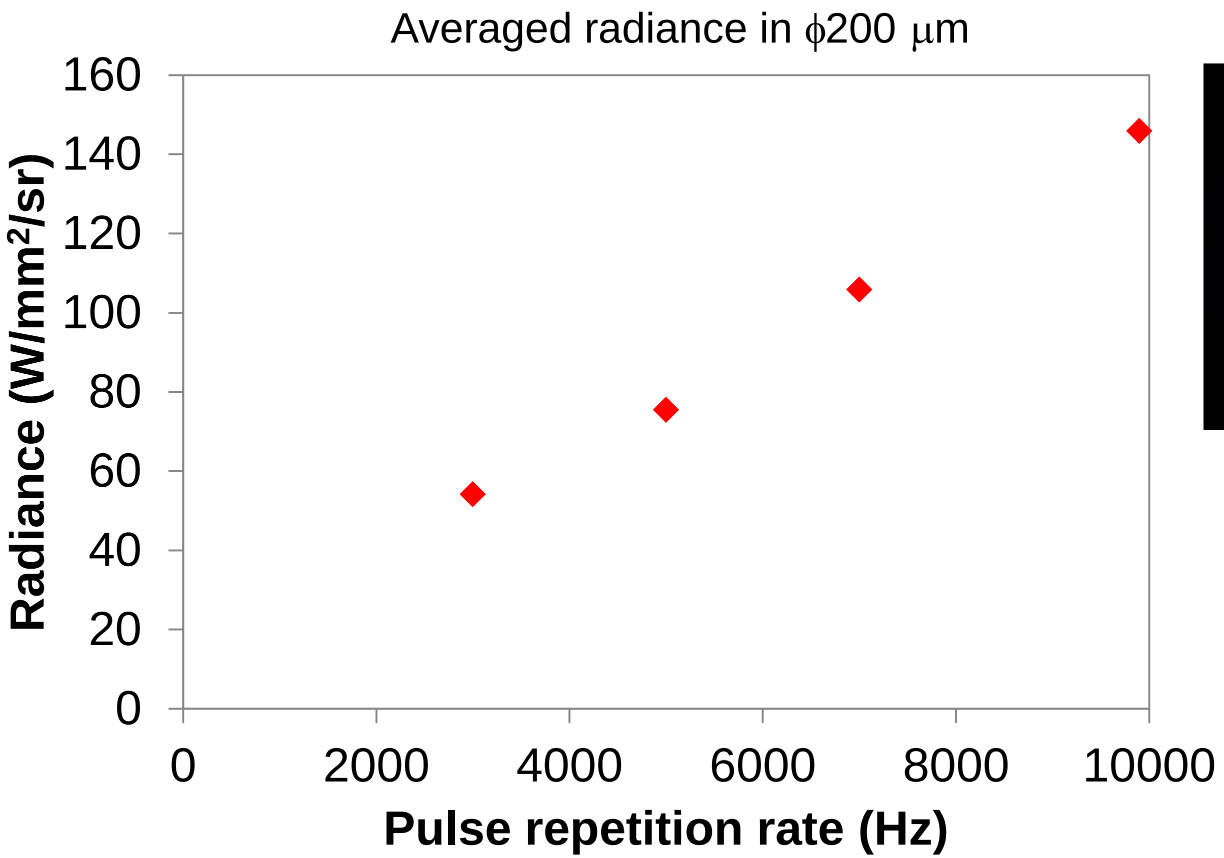


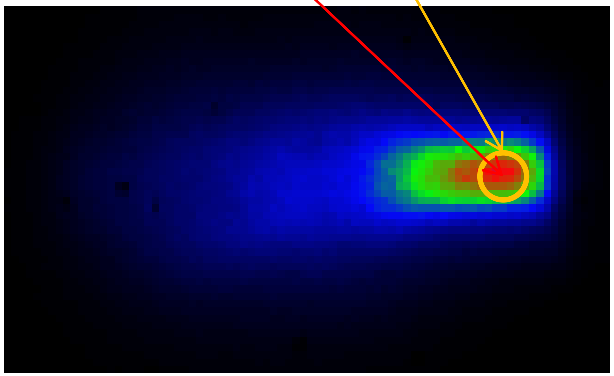
10 kHz, continuous operation

- ❑ Diameter: 200 μm (FWHM)
- ❑ Length: 450 μm (FWHM)

EUV radiance without debris shield (at plasma)

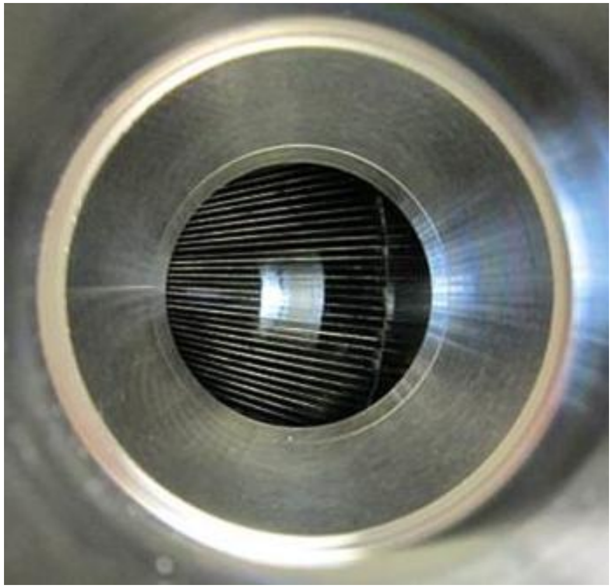
- Peak radiance: 180 W/mm^2/sr
- Area-averaged radiance: 140 W/mm^2/sr



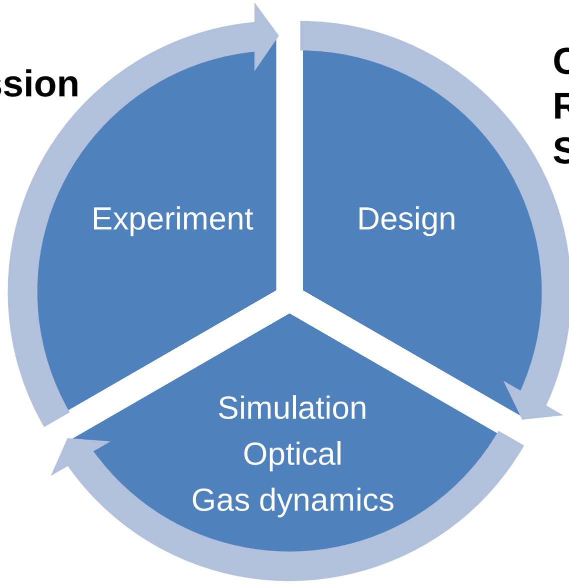


15 kW (10 kHz)

Debris shield



Transmission
Debris suppression

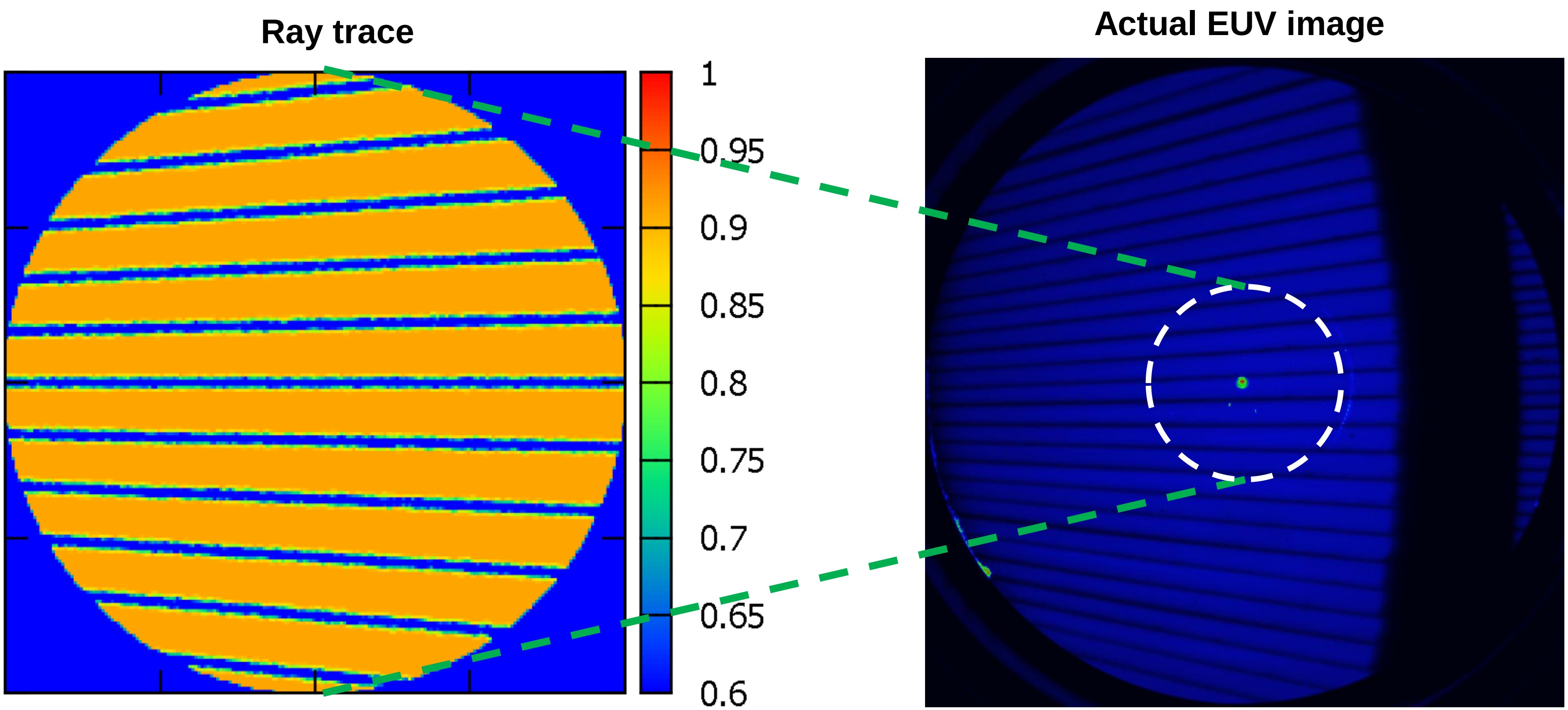


Compatibility
Robustness
Serviceability

Transmission
Uniformity
Gas pressure

Far-field beam pattern behind debris shield

- Experimental debris shield was modified and tested.
- Overall transmission has been improved by 6 % (FEB'14: 71 % → NOW: 77 %).

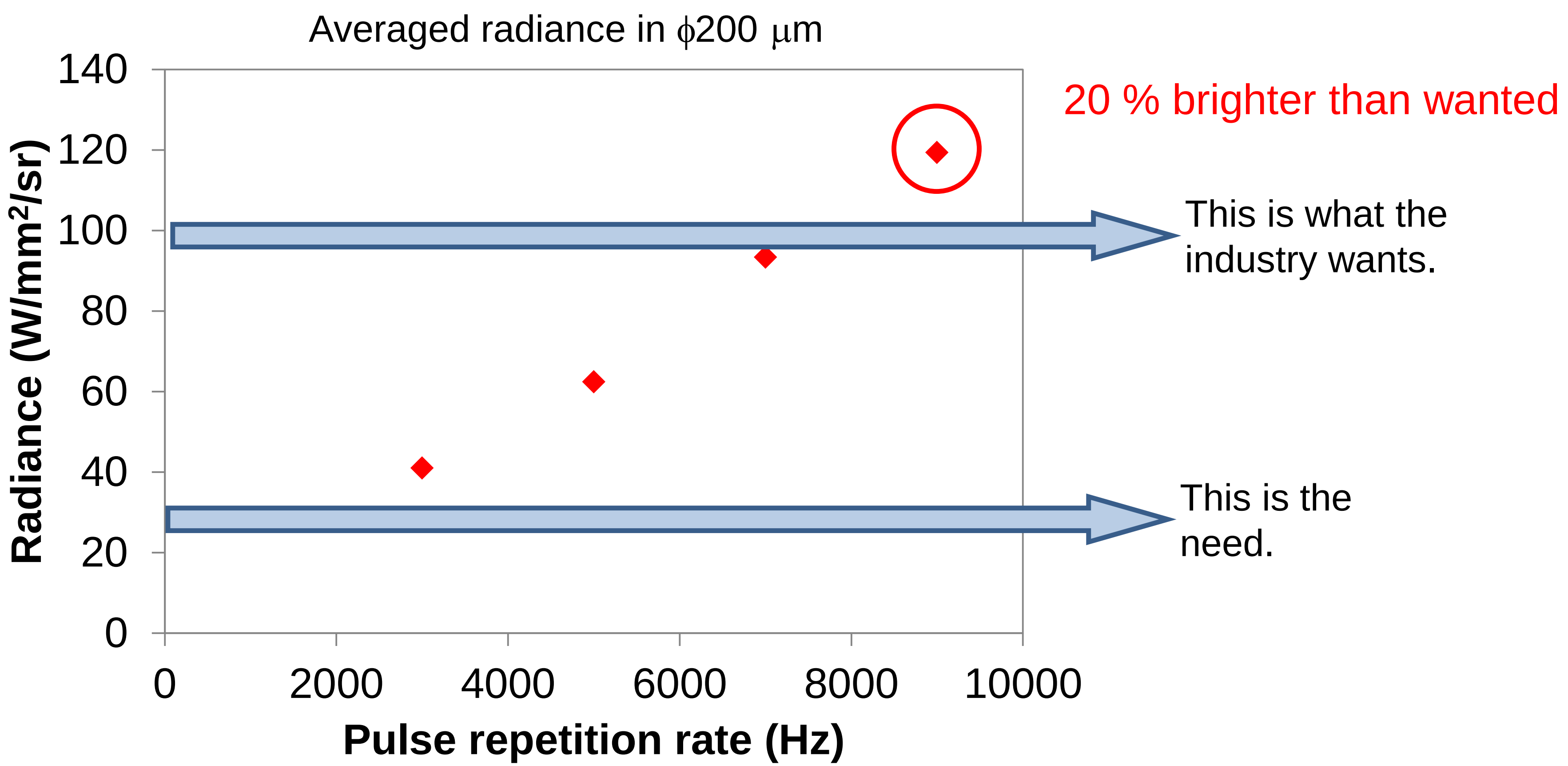


Transmission 83 %

Transmission 77 %

Measured EUV radiance behind debris shield

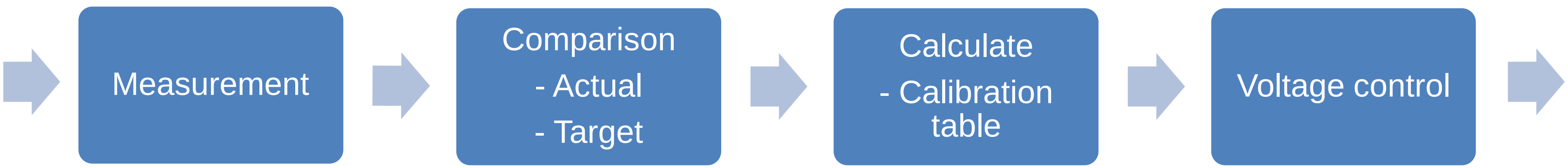
Measured behind debris shield as clean EUV photon
- Peak radiance: 145 W/mm^2/sr
- Area-averaged radiance: 120 W/mm^2/sr

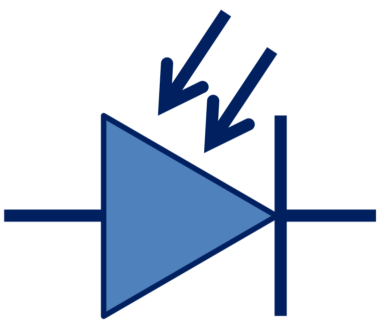


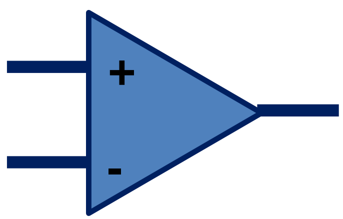
I N D E X

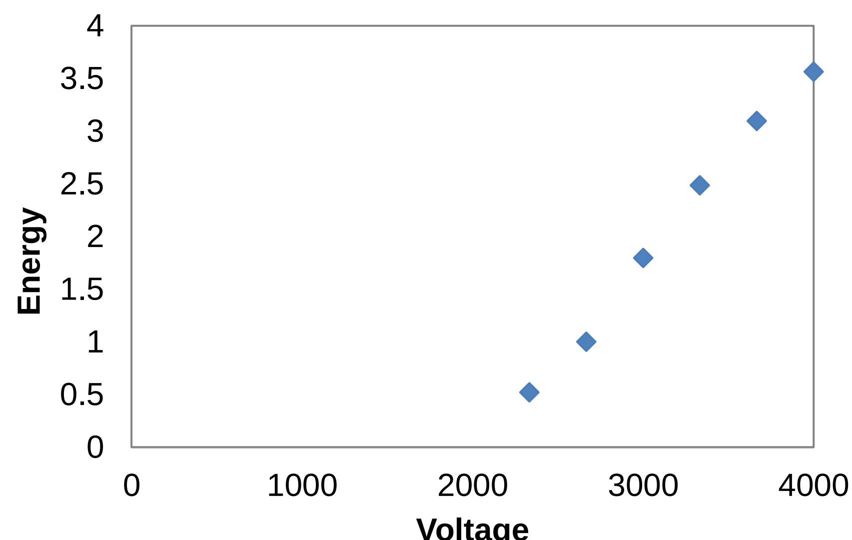
Energy and radiance vs voltage for feedback control

- ❑ Feedback control to stabilize energy dose
  - ❑ Time window is specified by the tool.
- ❑ Pulse-to-pulse energy measurement and voltage control.
  - ❑ Radiance can also be used as a target value.









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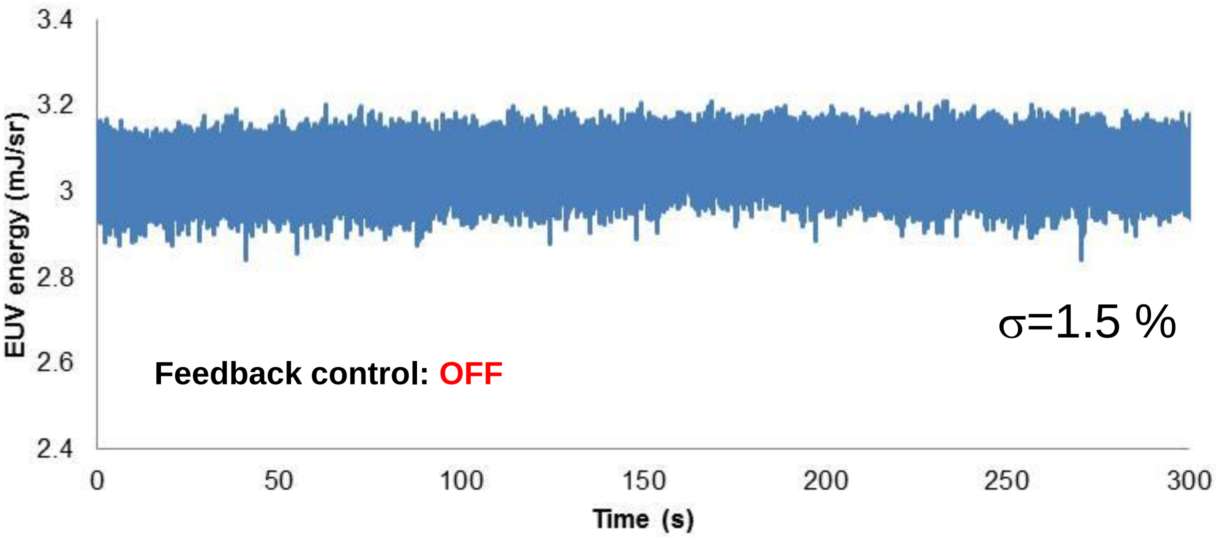
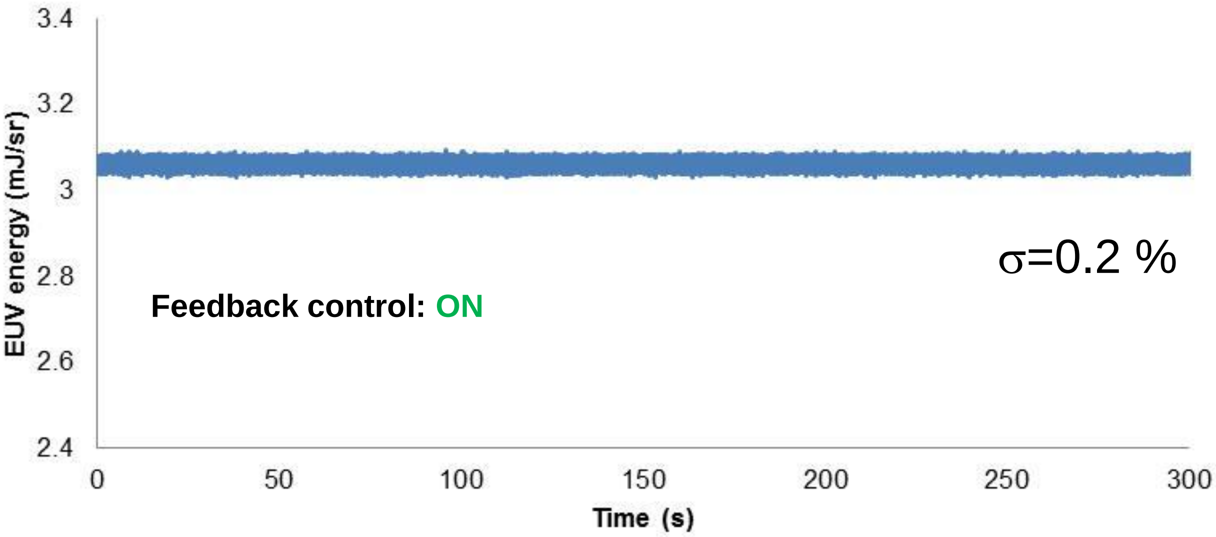
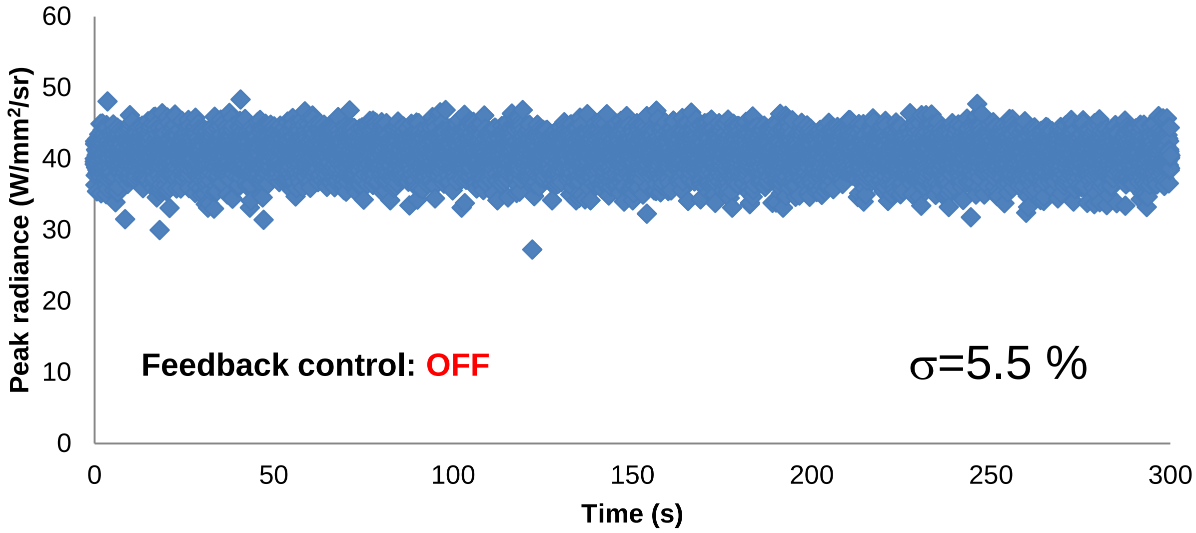
EUV energy stability

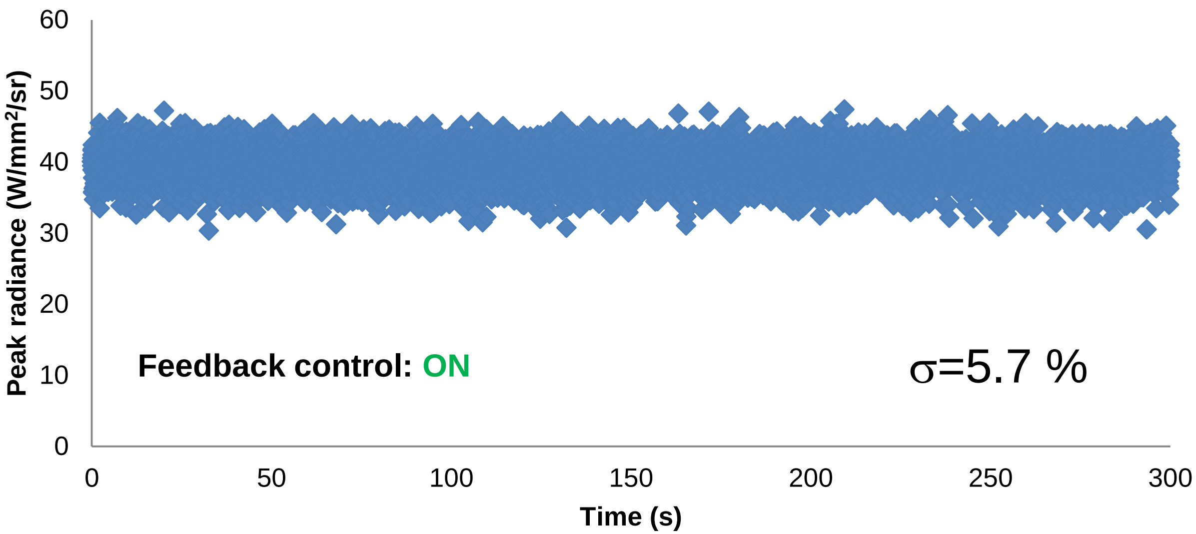




- 3 kHz, DC 100 %
- 40 $W/mm^2/sr$
- A certain dose specification assumed

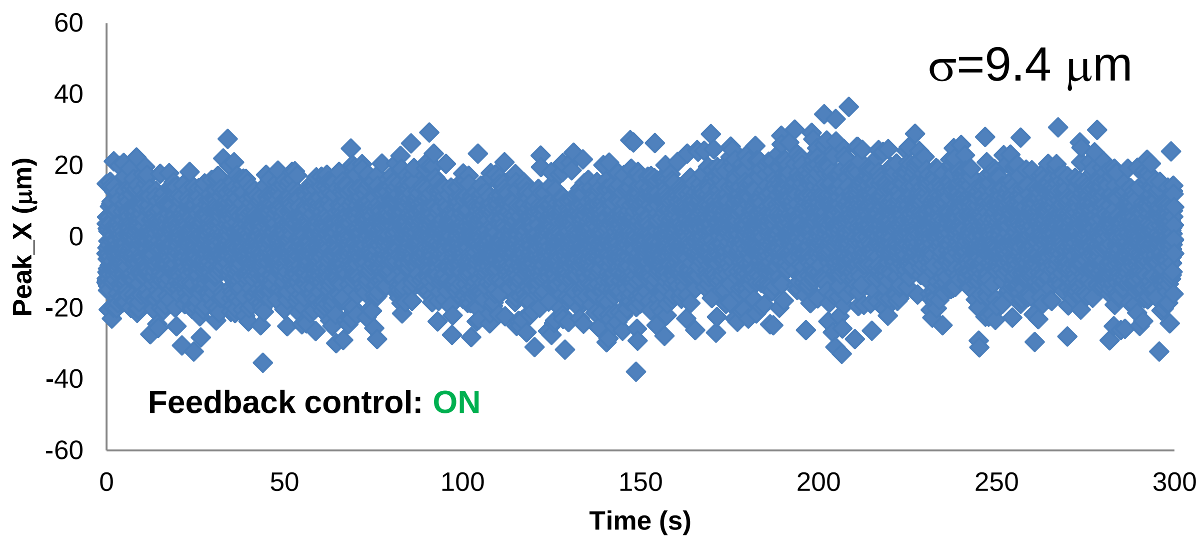
EUV radiance stability

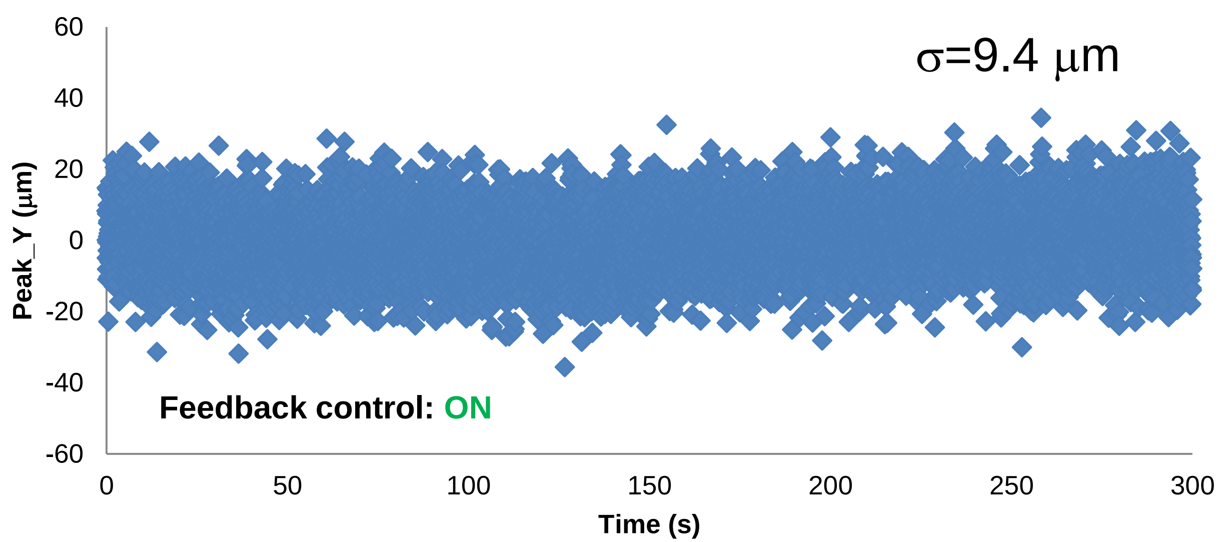




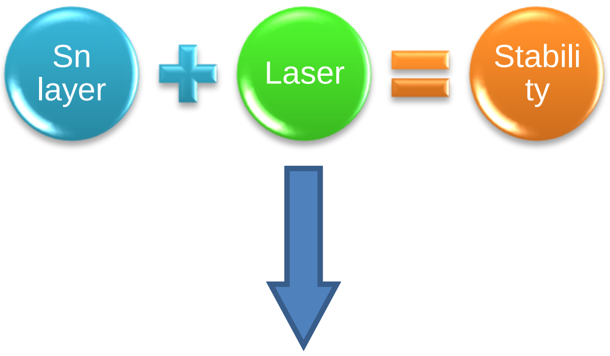
- 3 kHz, DC 100 %
- 40 W/mm^2/sr
- Non-synchronized EUV camera

Position stability





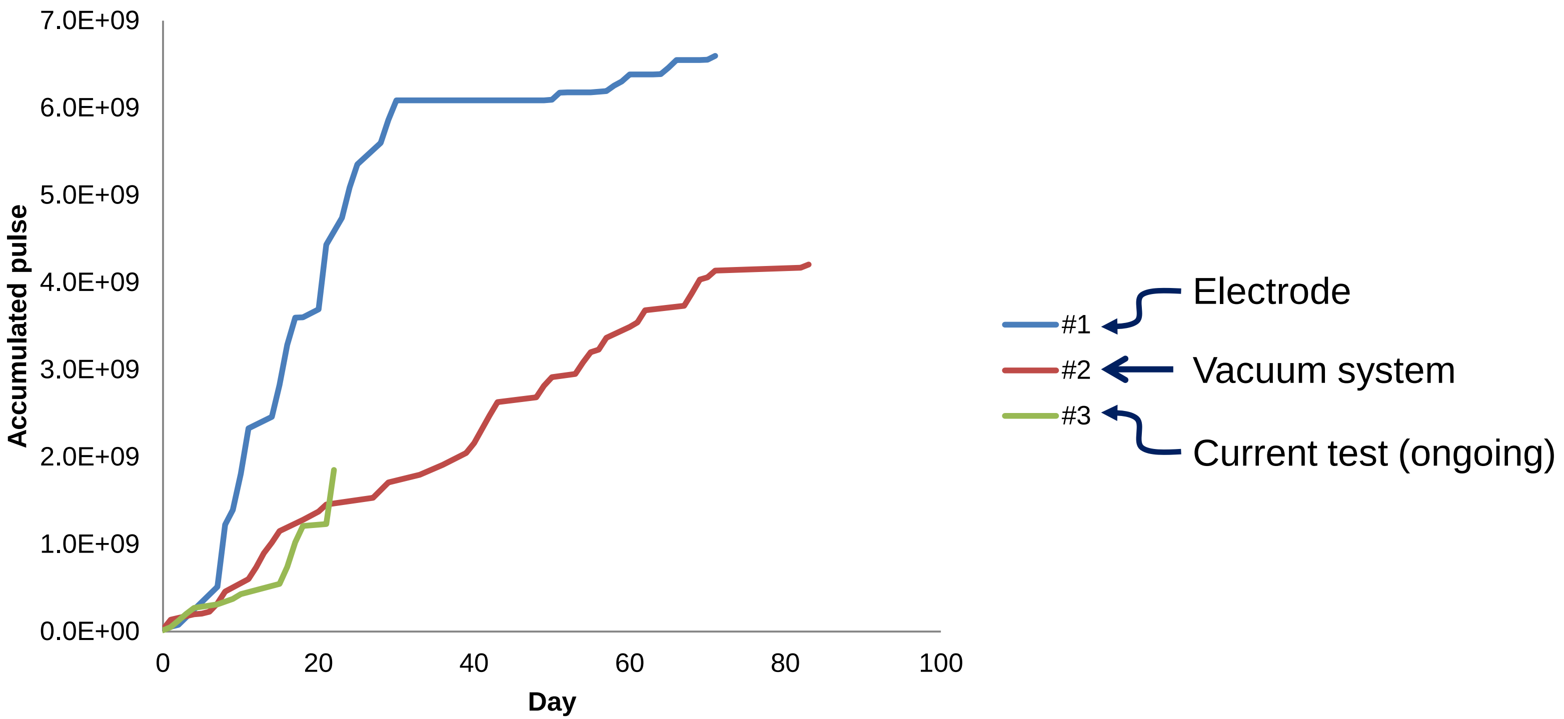
- 3 kHz, DC 100 %
- 40 W/mm²/sr
- Non-synchronized EUV camera



Energy/position stability improvement

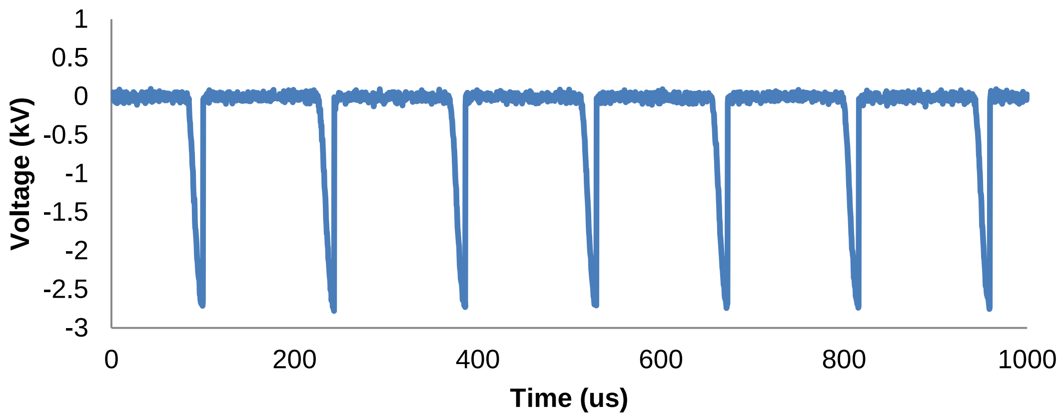
Key component reliability

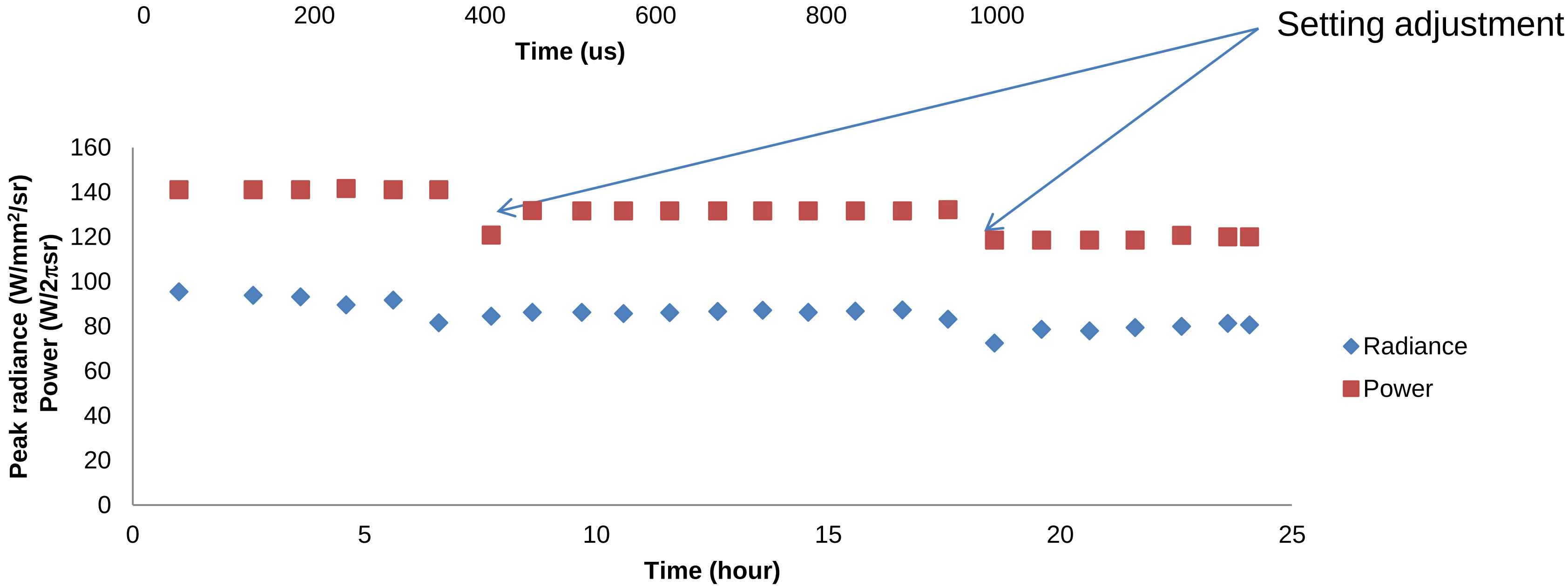
- ❑ 4~6x10^9 pulses to major failure in the past tests.
  - ❑ Equivalent to 15~23 days at approx. 40 W/mm^2/sr of radiance.
- ❑ Test is being continued.
- ❑ Further tests will be carried out using a dedicated machine.



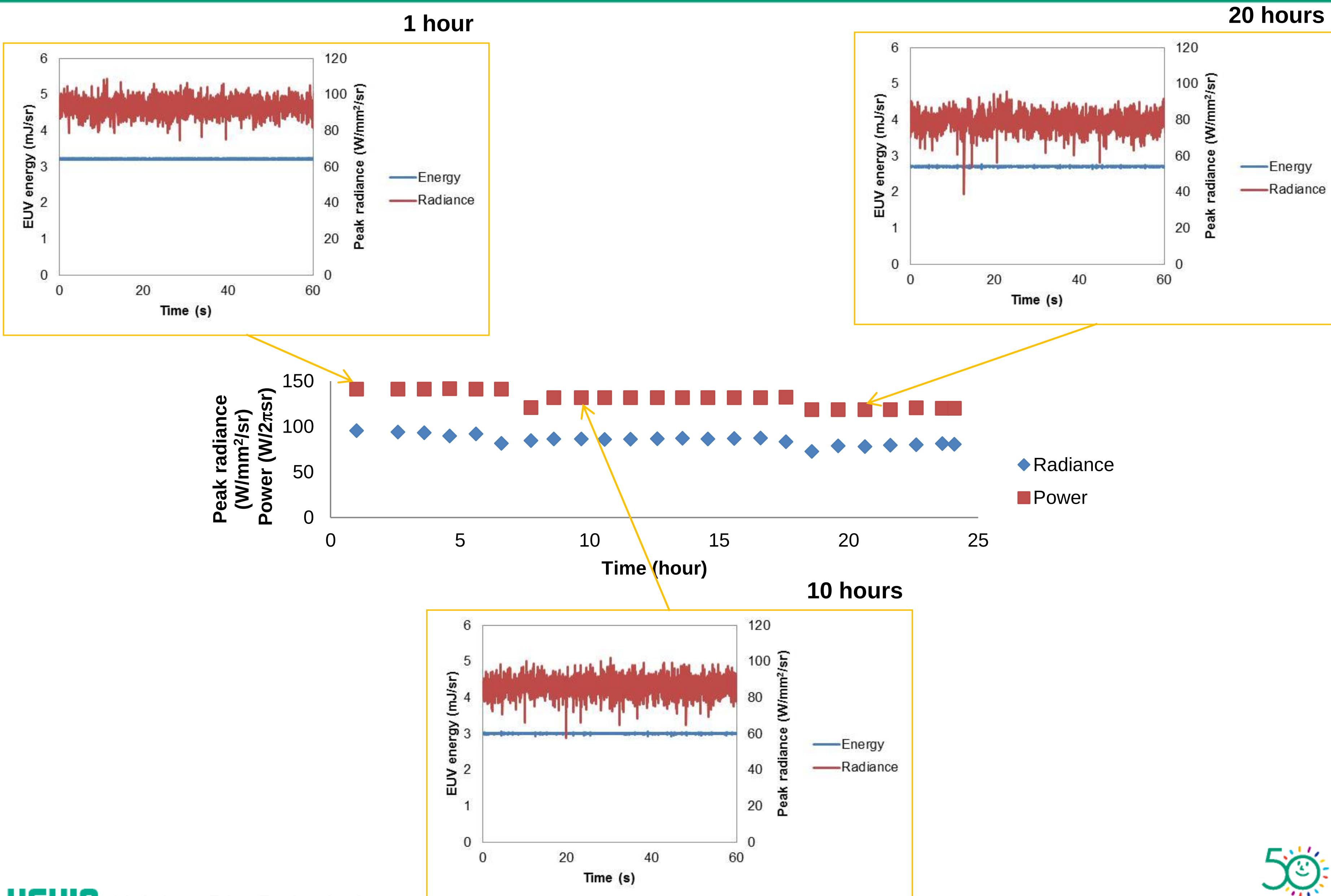
Long-term power trend

- System ran at 7 kHz, 100 % duty cycle for 24 hours without interrupt.
- Feed-back control was activated.





Long-term power trend



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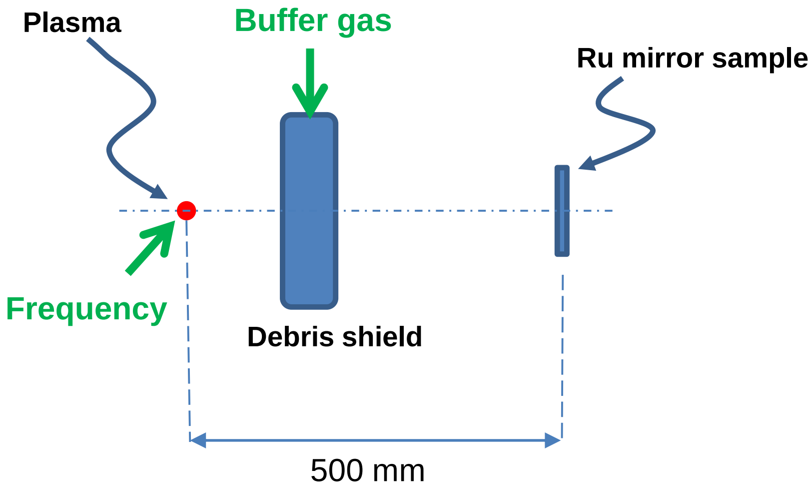
Sputtering and deposition: experiment



Discharge frequency:	5, 7 and 9 kHz
Buffer gas:	Variable
Sample:	8-nm-thick Ru on Si
Source-sample distance:	500 mm
Incidence angle:	90°
Analysis:	XRF

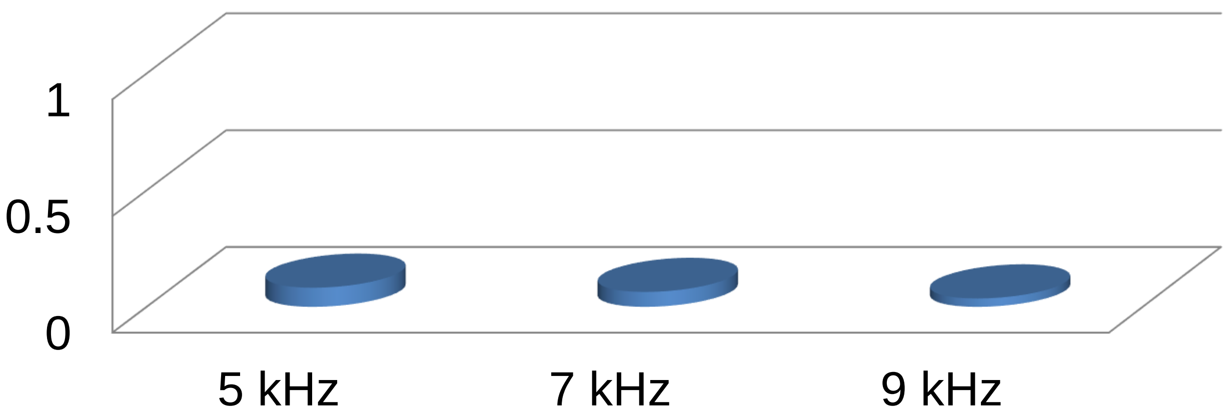
After 100~500M pulse

Sputtering and deposition: result

Sputter rate (nm/Bpulse)

- There is an erosion due to ions passing through the debris shield.
- Erosion progresses at the pace of <3 nm/Bpulse.

Deposition (nm)



- There is a slight deposition of Sn.
- However, according to the experiments done so far, it does not grow and stops around at 0.1 nm.

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Summary

- Radiance behind debris shield (clean photon) was confirmed to be as high as 120 $W/mm^2/sr$.
  - It is sufficiently high to satisfy requirements of all mask inspection applications.
- Energy stability control
  - 0.2 % of energy stability was confirmed.
- Long-term stability
  - 24-hour test was done at 7 kHz with energy stability control on.
- Cleanliness (optics lifetime)
  - Sputter rate and deposition rate were found to be significantly low.